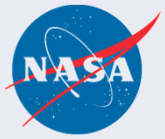

Desirements of Next Generation Spacecraft Interconnects: The JPL *NEXUS Perspective*

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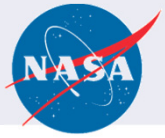
California Institute of Technology/Jet Propulsion Laboratory

Spacecraft Interconnect Workshop
2011 GOMACTech
Orlando, Florida
March 23, 2011

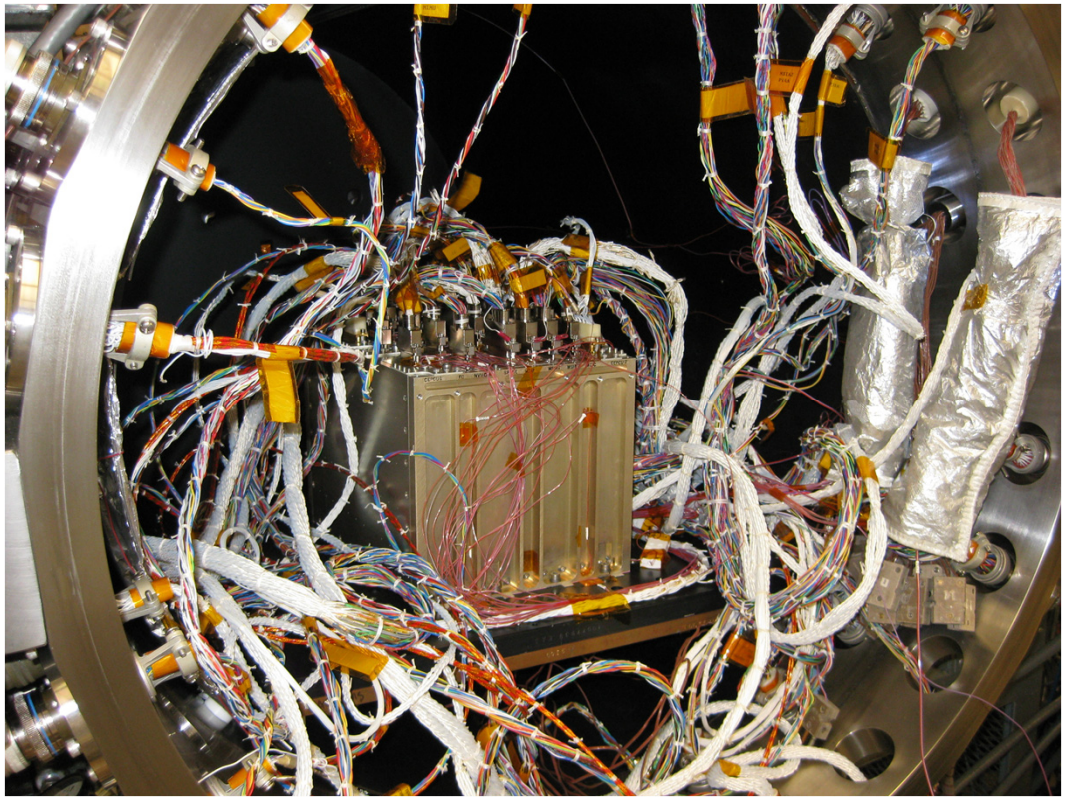


Outline

- Motivation
- Technical Approach
- Desirement Breakdowns
- Summary

Motivations

So, why are we here?

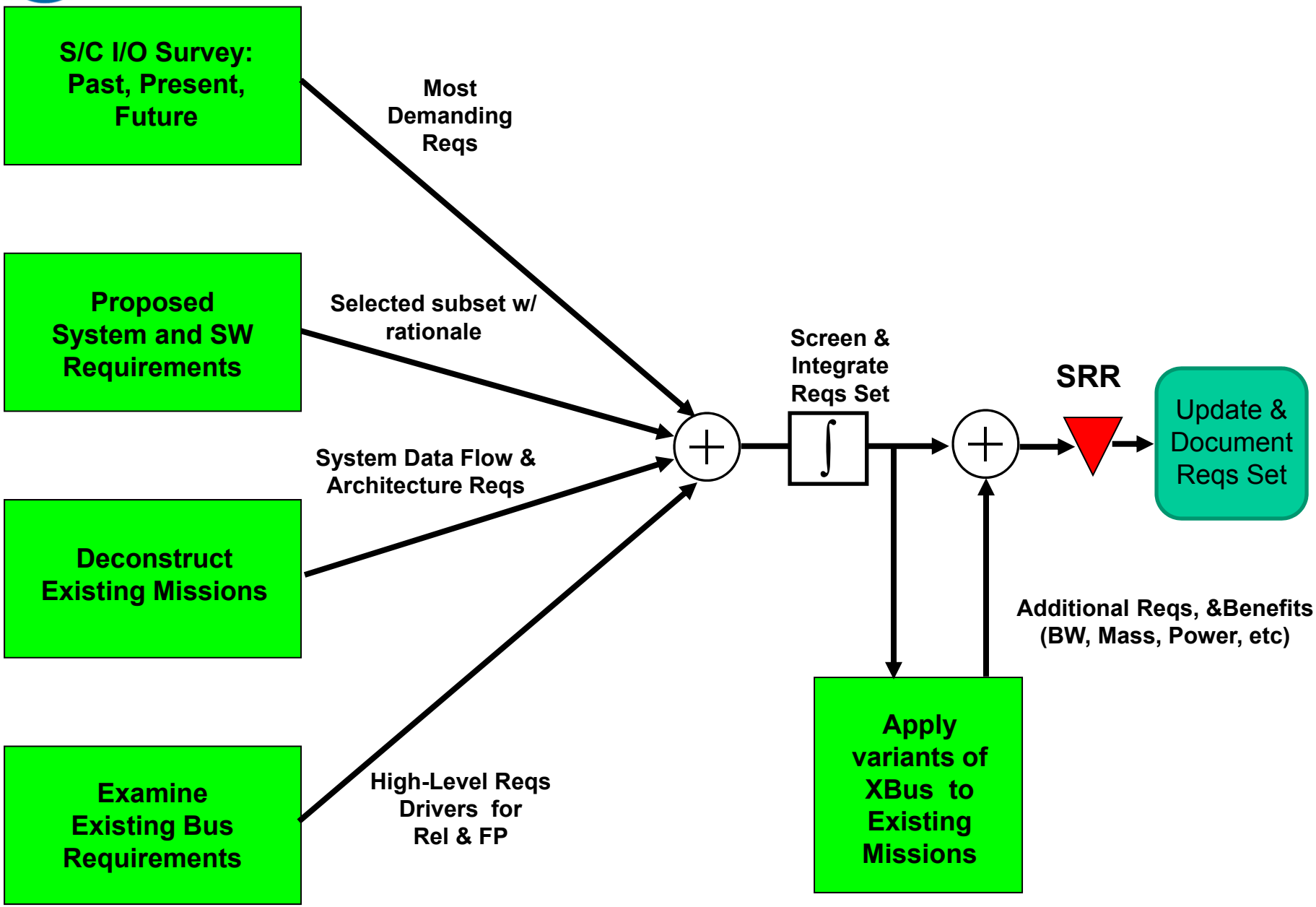


And what should we do in the future?

Objectives

- *NEXUS* (NEXt bUS)
  - A research task funded by JPL R&TD program
  - Develop a common highly-capable next generation avionics interconnect with the following features:
    - ❑ Transparently compatible with wired, fiber-optic, and RF physical layers
    - ❑ A clear and feasible path-to-flight to ensure infusion into future NASA/JPL missions

Technical Approach for Desirement Capture



Survey of 15 Representative Missions

- 15 past, current, and future space missions were surveyed with respect to its interconnect desired capabilities

Mission Name	Program	Mission Characteristics			Avionics Characteristics
		Timeframe	Destination	Type	
1	Planetary	Near Term	Planetary	Lander	Multi-stage, Dual-string C&DH
2	Planetary	Long Term	Planetary	Rover	Multi-stage, Low mass, Motor control
3	Planetary	Long Term	Planetary	Rover	Low mass, low power, motor control
4	Astro-Physics	Near Term	Earth	Interferometer	Distributed determistic precision control
5	Astro-Physics	Near Term	Earth	Robotic	Distributed determistic precision control
6	Earth Science	Near Term	Earth	Orbiter with L-band Radar	> 30 Mbps Instrument I/F, > 80 Mbps Downlink
7	Earth Science	Long Term	Earth	Orbiter with InSAR	> 3 Gbps instrument I/F, >5 TB on-board storage, on-board processing
8	Lunar	Long Term	Lunar	Robotic/Human	Dual self-checking computer pairs
9	Lunar	Long Term	Lunar	Human	Lunar Surface Systems
10	Planetary	Long Term	Planetary	Orbiter	Gbps instrument I/F, 12 TB on-board storage, Gbps downlink rate
11	Planetary	Long Term	Planetary	Orbiter	Dual-string
12	Planetary	Long Term	Planetary	Orbiter	High radiation, dual string, long-life
13	Astro-Physics	Long Term	Planetary	Space Telescope	2 formation-flying S/C; 12 TB on-bard storage, Gbps instrument I/F and downlink rate
14	Astro-Physics	Long Term	Earth	Robotic	Fractionated S/C
15	Astro-Physics	Near Term	Asteroid Belts	Robotic	Dual-string

Survey Format

Avionics Bus	Interfaces								
Attributes	**Instrument**	**ACS/GN&C**	**Telecom**	**RTC**	**Motors**	**Human**	**C&DH Std Interfaces**	**Power/Pyro**	**Power Internal**
Bandwidth Note: S/C Aggregate 190 Mbps *	152Mbps LVDS/RS422	1MHz 1553EDL	36Mbps LVDS 1MHz 1553EDL 1MHz 1553Rover	N.A.	1MHz 1553EDL	N/A	1MHz 1553EDL 1MHz 1553Rover	1MHz 1553EDL 1MHz 1553Rover	RSB Bus: 1 Mhz.
Latency		16ms	16ms	N.A.	125ms	N/A	16ms	16ms	
Jitter		1μs	1μs	N.A.	1μs	N/A	1μs	1μs	
Scalability (# of nodes)		31	62	N.A.	31	N/A	62	62	
Topology	Point-to-Point	Bus & Parallel	Bus & Parallel	N.A.	Bus & Parallel	N/A		Point-to-Point Parallel	
Fault Tolerance	YES	YES	YES	N.A.	YES	N/A	YES	YES	Dual
Hard Real-Time	NO	YES	YES	N.A.	YES	N/A	YES	YES	
EMI Sensitivity	YES	YES	YES	N.A.	YES	N/A	YES	YES	
Transfer Mode	Duplex	Duplex	Duplex	N.A.	Duplex	N/A	Duplex	Duplex	
Max Node Spacing (m)	20m	15m	20m	N.A.	20m	N/A		20m	
Desired Power Modes	On/Off			N.A.		N/A			
Testability Features	1553GSE	1553EDLTest	1553Test Port	N.A.	1553Test Port	N/A		1553Test Port	
Importance of Isolation	yes	yes	yes	N.A.	yes	N/A	yes	yes	
Statically/Dynamically Allocated Bandwidth	Static	Static	Static	N.A.	Static	N/A	Static	Static	Static
Fiber Optical Advantages	Yes	Yes	Yes	N.A.	Yes	N/A			Yes
Wireless Advantages				N.A.	Yes	N/A			
PHY Compatibility				N.A.		N/A			
Radiation Level (TID)	Mars	Mars	Mars	N.A.	Mars	N/A	Mars		Mars
Temp Range - Op				N.A.		N/A			
Temp Range - Non Op				N.A.		N/A			
Baseline Bus	p-to-p	1553	1553 &LVDS	N.A.	1553	N/A	cPCI	1553	RSB
Desired Protocol Layer Support				N.A.		N/A			
Watts/Node		1.7	1.7	N.A.	1.7	N/A	N/A	1.7	
Total power consumption (W)	10	1.7	5.1	N.A.	3.4	N/A		6.8	
No. of nodes		1	3	N.A.	2	N/A		4	
Type of nodes	RT	RT	RT	N.A.	RT	N/A		RT	

* Total “simultaneous” data flow (hypothetical; assume all I/Fs are active at full capacity)

Rollup of Missions by Subsystem Drivers

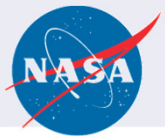
Illustrated with a hypothetical mission

Mission Summary

Mission Survey Data

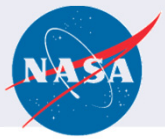
Attribute	Instrum.	ACS, GN&C	Telecom	OnBoard Storage	Motors	Human	C&DH Std I/Fs	Power / Pyro	Real Time Control	Mission Summary Column
1		X								X
2	X									X
3			X							X
4					X					X
5				X						X
6						X				X
7							X			X
8								X		X
9									X	X

- "X"s in the table represent the most demanding mission parameters
- The "X" values with color code are inserted in the Summary Column
- The color coding preserves the origin of the driving subsystem
- "Mission Summary Columns" for all missions surveyed are below



Key Survey Findings

- Aggregate bandwidth is orders of magnitude greater than traditional avionics “backbone” buses like 1553B or SpaceWire
- Instruments are the biggest drivers on bandwidth, and are expected to be even more so in the future
- Instruments requiring coordinated precision is the biggest driver in real-time performance
- Missions with complex operation scenarios are big drivers in C&DH and ACS
- Need to accommodate physical separation events is a large driver for many future S/Cs
- Hybrid ad-hoc solutions lead to a overwhelming interconnect maze that complicates design, integration, and testing, and increase wire mass and power consumption



Other Sources of Inputs

- **Proposed System and SW Requirements**
  - Initiated by a “Laundry List” submitted by systems engineers
  - We ensured that every requirement had a rationale, and provided a justification for requests that were not accepted
  - The entire data base (included rejected requirements) is archived
- **Deconstruction of S/C Avionics for some missions**
  - A top-down deconstruction of the avionics architecture for existing missions were executed
  - A list of drivers to support the avionics architecture was synthesize
- **Examination of Existing Bus Requirements**
  - MIL-STD-1553 and the Cassini CDS S/S requirements were reviewed for fault protection and reliability issues.
  - A subset of specific requirements in these areas were collated
  - In order to utilize these specific and detailed requirements for our needs, they were adapted into “Generic” fault protection and reliability requirements

NEXUS Desirements Categories

No.	Requirement Categories
1.0	Physical Layer Compatibility
2.0	Operational Mode
3.0	Protocol
4.0	Topology
5.0	Scalability
6.0	Reconfiguration
7.0	Modularity
8.0	Commercial Standard Compatiblity
9.0	Legacy System Compatiblity
10.0	Bandwidth
11.0	Real-Time Operation and Control
12.0	Fault Tolerance Level
13.0	Fault Detection
14.0	Fault Response
15.0	Testability
16.0	Electrical Isolation
17.0	Power/Bandwidth Management
18.0	Radiation Level
19.0	EMI Sensitivity
20.0	Temp Range Op & Non-Op

Notes:

1. The categories are listed from high-level to low-level; i.e., from generic to specific

2. The ordering does not reflect the importance of the categories

Key NEXUS Desirements Highlights

NEXUS-001: The NEXUS shall be compatible with wired, fiber-optic, and RF physical layers.
NEXUS-002: The NEXUS shall be light-weight.
NEXUS-003: The NEXUS shall be power scalable with bandwidth.
NEXUS-004: The NEXUS shall be fault-tolerant.
NEXUS-005: The NEXUS shall provide a scalable bandwidth from 1Mbps to 10 Gbps.
NEXUS-006: The NEXUS shall provide guaranteed real-time determinism with sub-microsecond latency and jitter.

Summary

- **We have captured the avionics interconnect desirements from the following sources:**
  - **Survey of 15 representative current and future flight missions**
  - **Inputs from Advanced Systems and Software**
  - **Deconstruction case study of avionics architectures of some missions**
  - **Examination of existing bus requirements**
- **We have developed and documented a sufficient set of 74 key avionics interconnect desirements composed of 20 categories**